Diurnal convection-wind coupling in the Bay of Bengal

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QuikSCAT, 1999–2009

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Motivation

The diurnal cycle is a fundamental mode of variability in the climate system.

Rainfall varies strongly with the diurnal cycle in much of the tropics.

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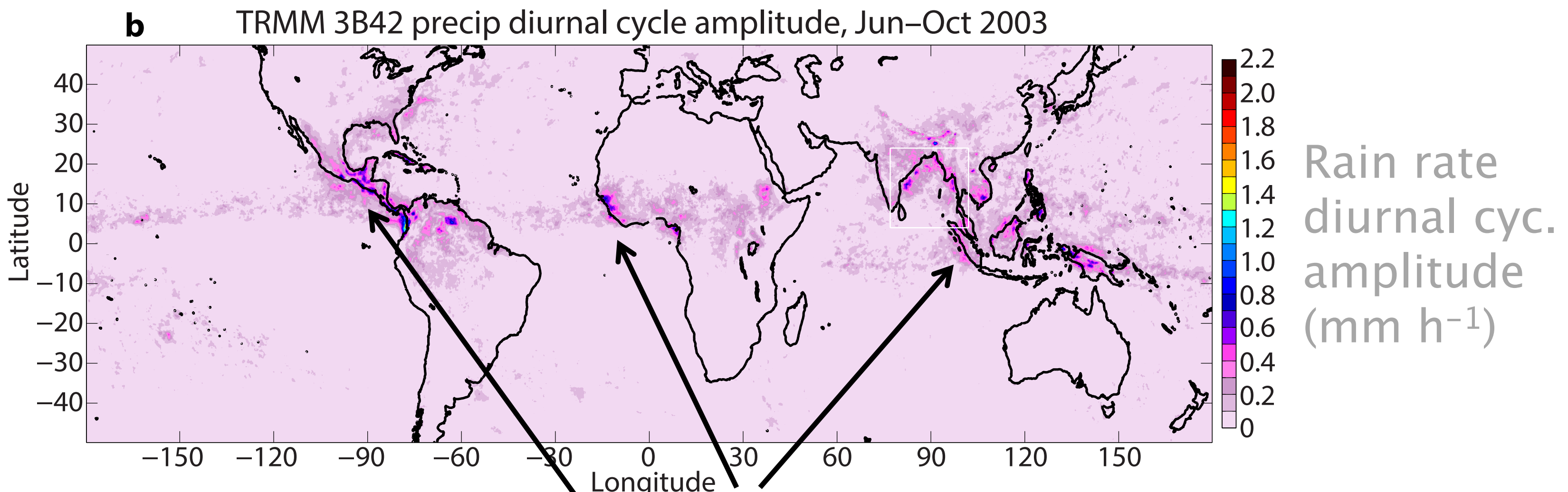
Better understanding of diurnal convection–wind coupling *at the process level* should help improve the representation of convection in climate models.

Bay of Bengal has one of the strongest diurnal cycles of rainfall in the world during the summer monsoon



Strongest diurnal cycles in coastal areas

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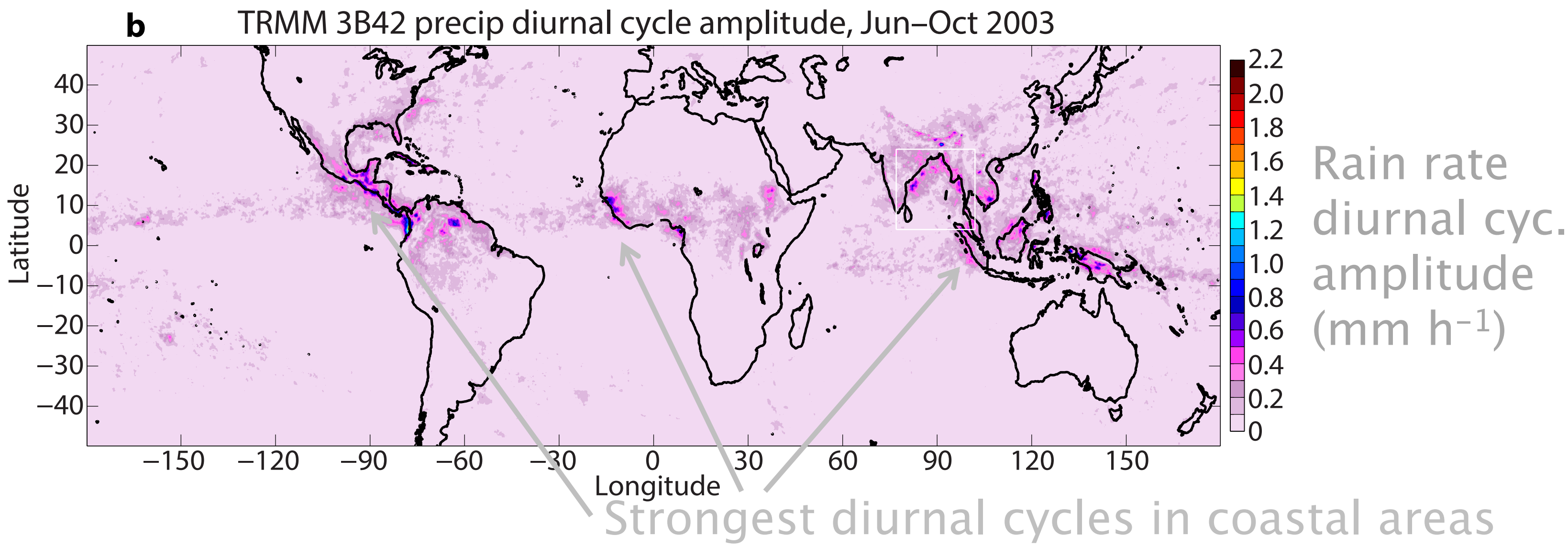
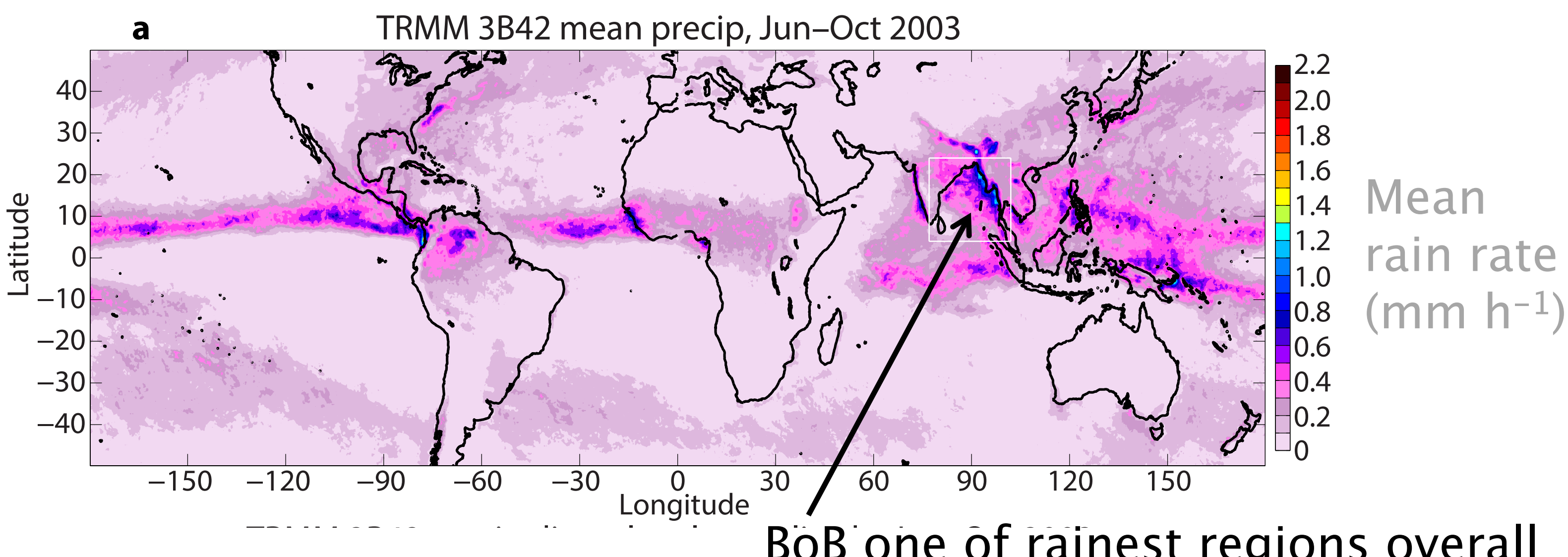
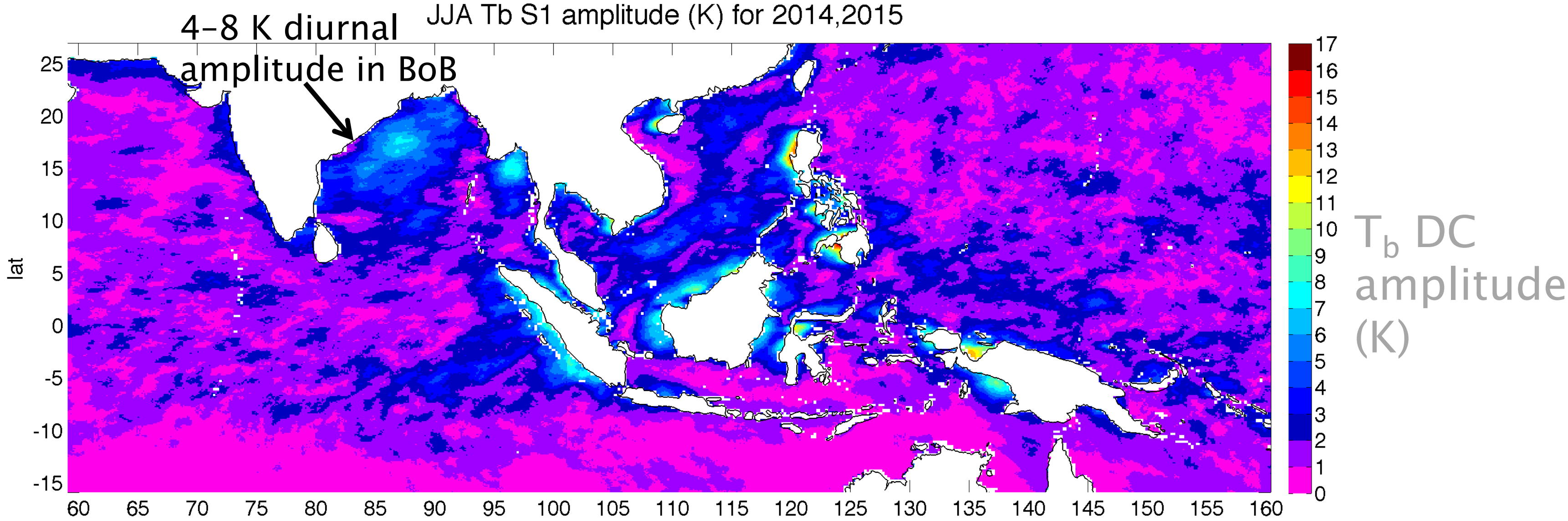




T_b shows diurnal offshore propagation in many coastal areas of the tropics



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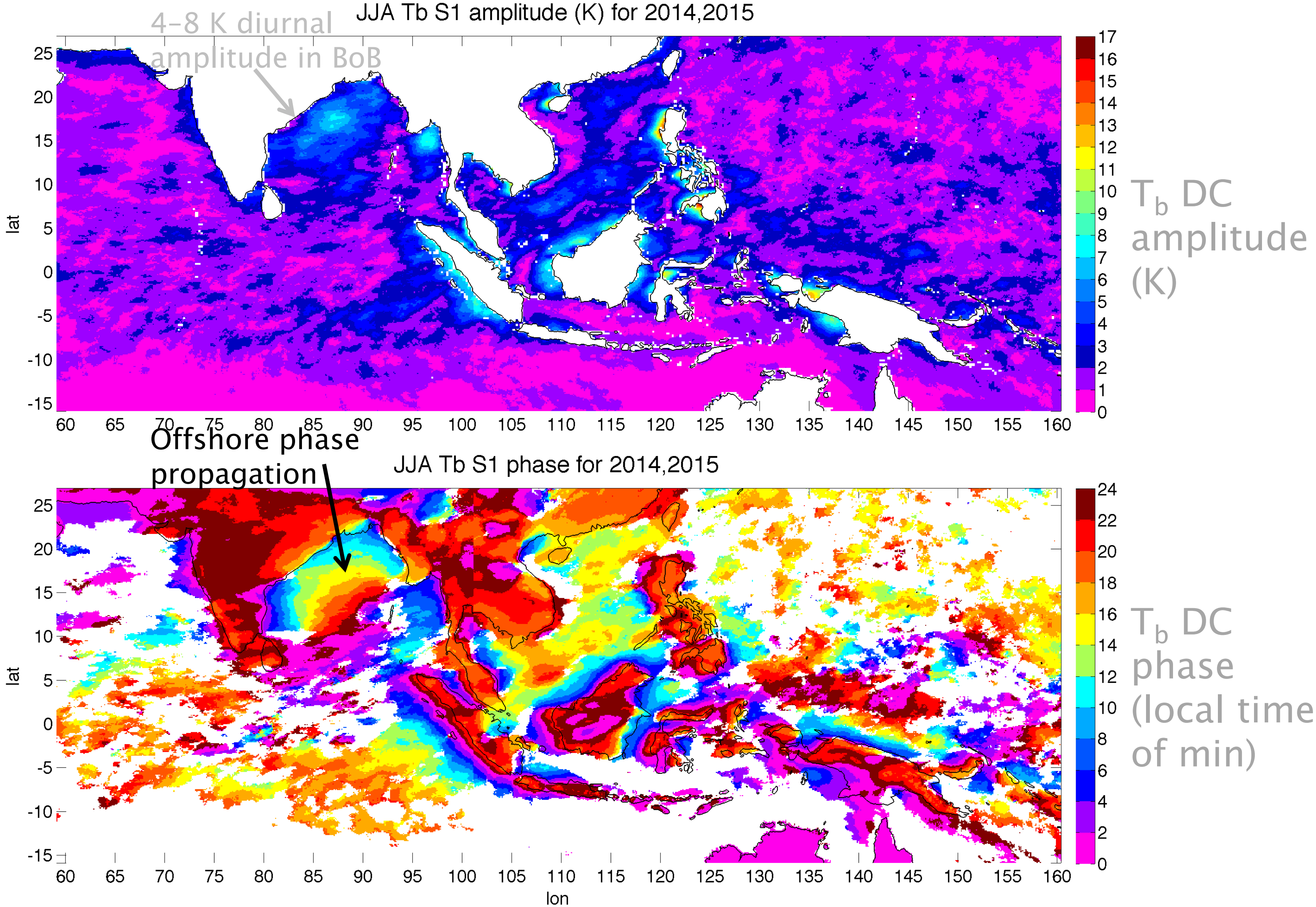

We utilize tandem mission and TMI winds to resolve diurnal wind variability

- Scatterometers (QuikSCAT, ASCAT, etc.) have generally flown on sun-synchronous orbits, limiting our ability to study diurnal wind variability from satellite.
- The tandem mission (Gille et al. 2005, Wood et al. 2009) and TMI (Wentz 2005) are two datasets that do resolve diurnal wind variability.
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- We focus on June-October 2003.
- LIFE processing (Kilpatrick and Xie 2016, JGR) increases wind data by ~10% over the bay by filling in rain-flagged patches.
- We fit wind data to diurnal harmonic via least-squares:

$$\delta = a\cos\left(\frac{2\pi t}{24\,\mathrm{h}}\right) + b\sin\left(\frac{2\pi t}{24\,\mathrm{h}}\right)$$

$$|\delta| = \sqrt{a^2 + b^2}$$

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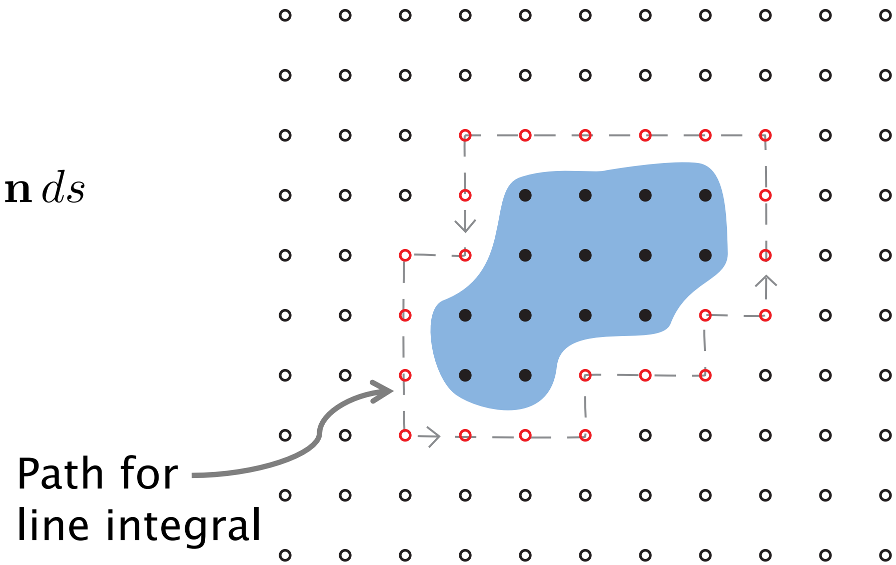
- Rainfall data are from the TRMM 3B42 product and TMI.

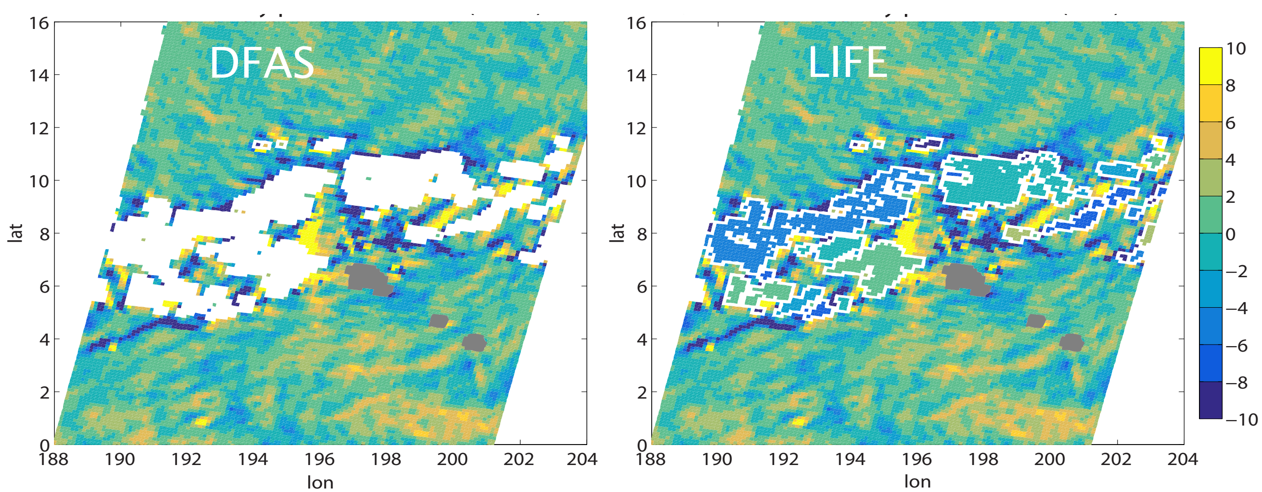
PSA: We can compute derivatives via line integrals *around* rainy patches

$$\mathrm{Div} = A^{-1}\int_A (\nabla \cdot \mathbf{u})\, dA = A^{-1}\oint_S \mathbf{u}\cdot\mathbf{n}\, ds$$

Kilpatrick and Xie (2016)
Bourassa and McBeth-Ford (2010)
Holbach and Bourassa (2014)



QuikSCAT wind vector cells

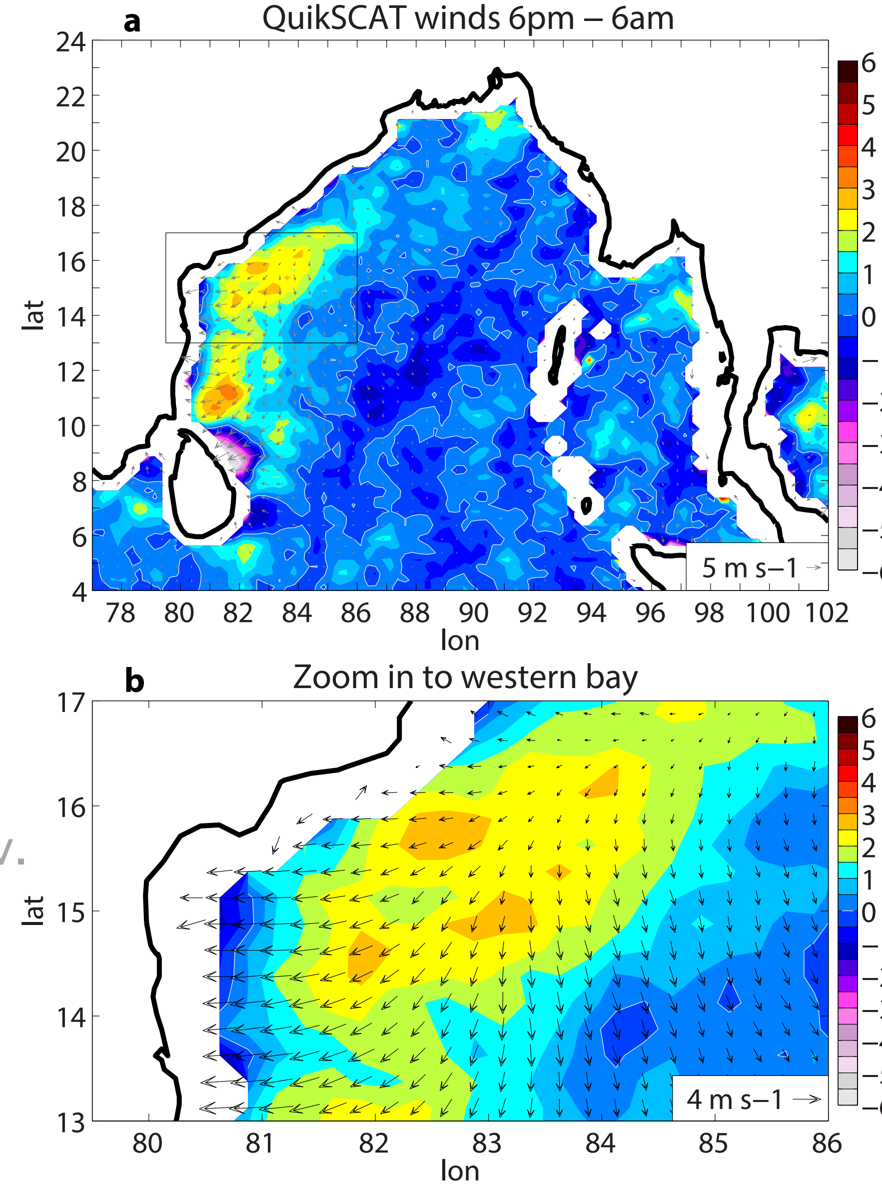


“Line integral, fill holes” (LIFE)

Tandem mission scatterometers detect a strong sea breeze in western Bay of Bengal

- QuikSCAT diurnal difference (18:00–6:00) shows well-developed sea breeze in *western bay only* (Gille et al. 2005, *GRL*).
- Previous analytical work has (wrongly) argued this east-west asymmetry is due to the mean southwesterlies (Li and Carbone 2015).

Color = div. ($\times 10^{-5}$ s^{-1})



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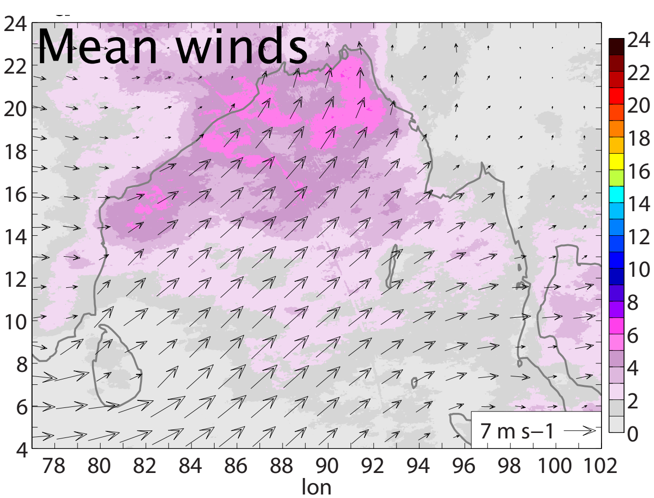

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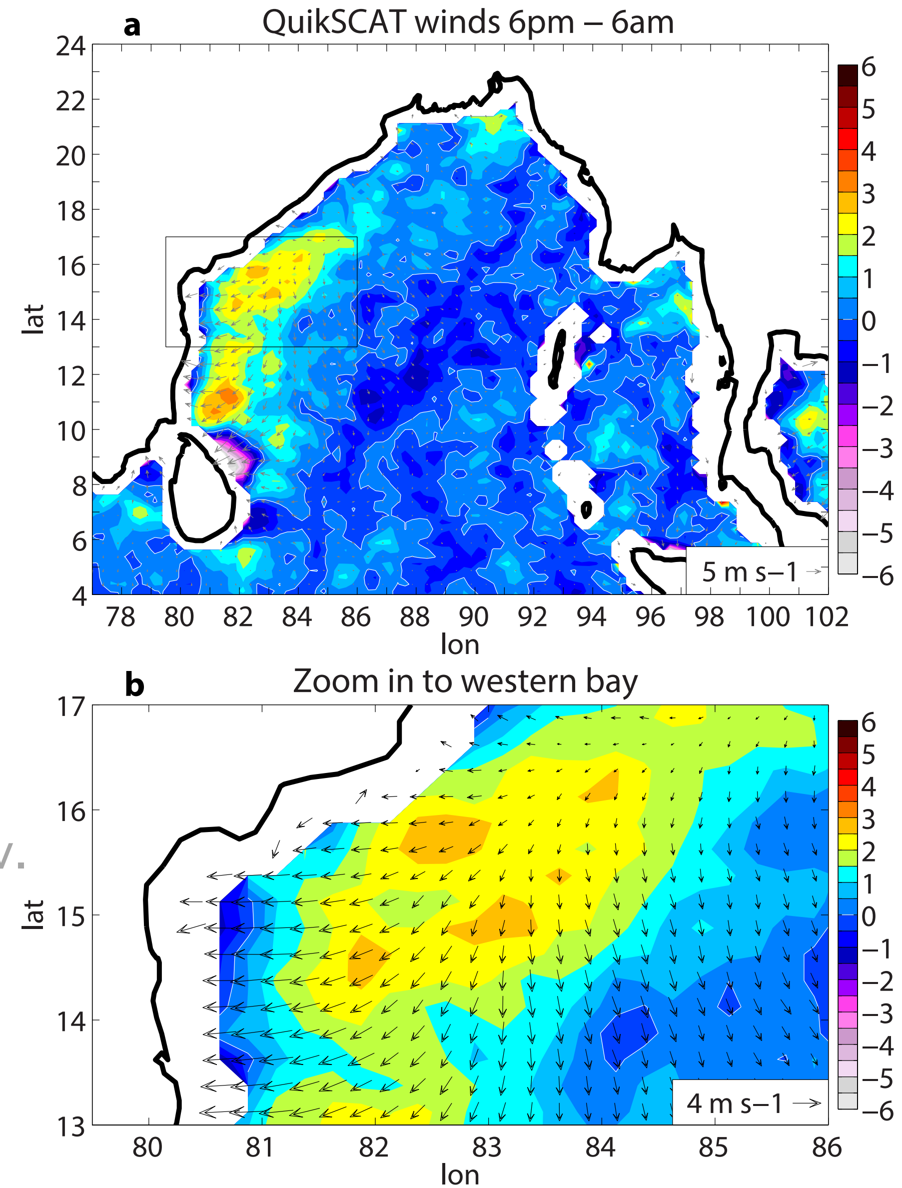
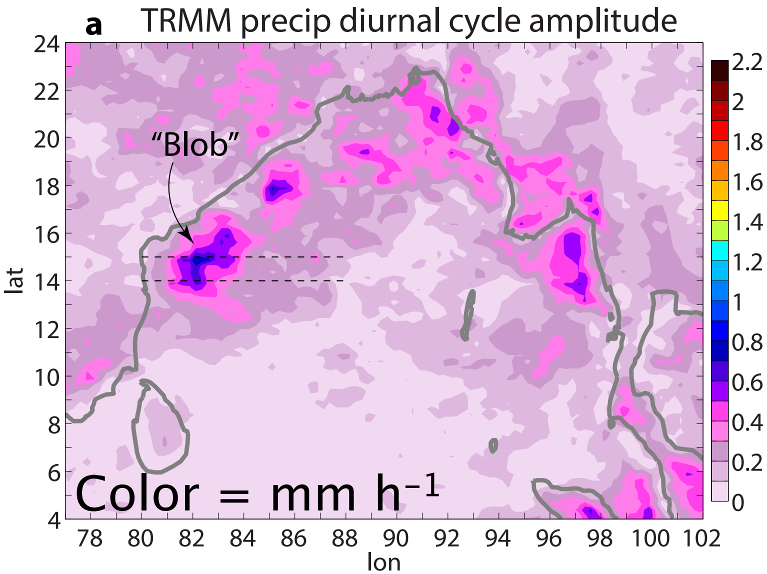


The land breeze and diurnal rainfall maxima co-propagate offshore in the western bay



- A "blob" of deep convection exists in the western bay, where nearly all the rainfall varies diurnally.

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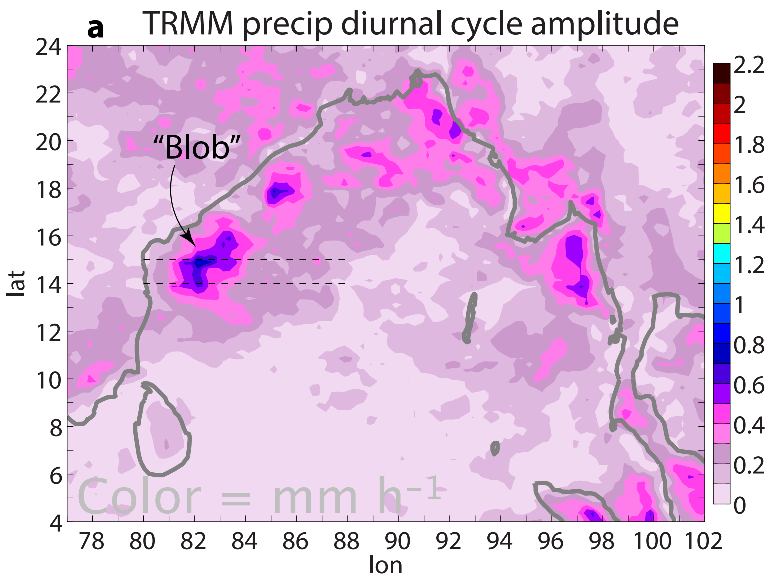
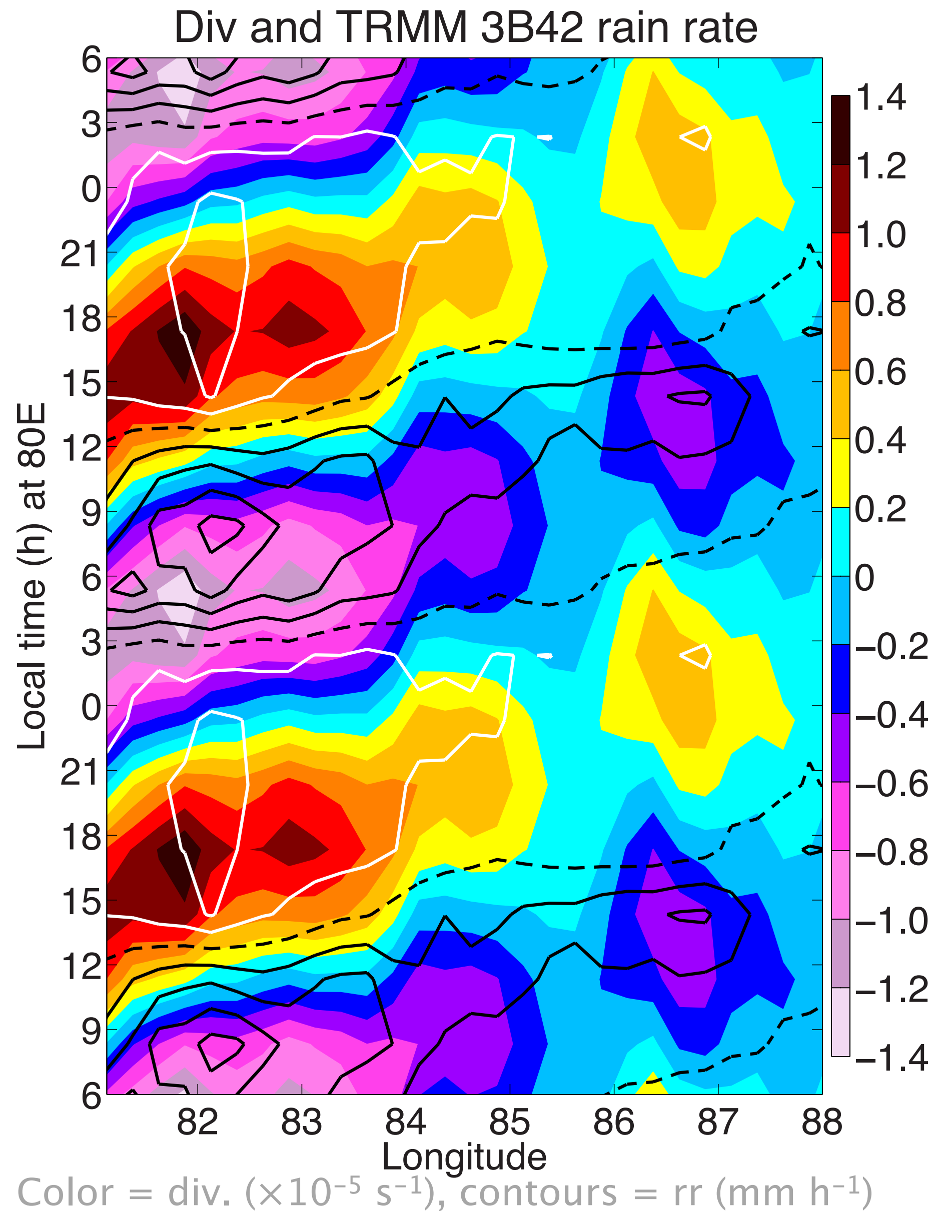
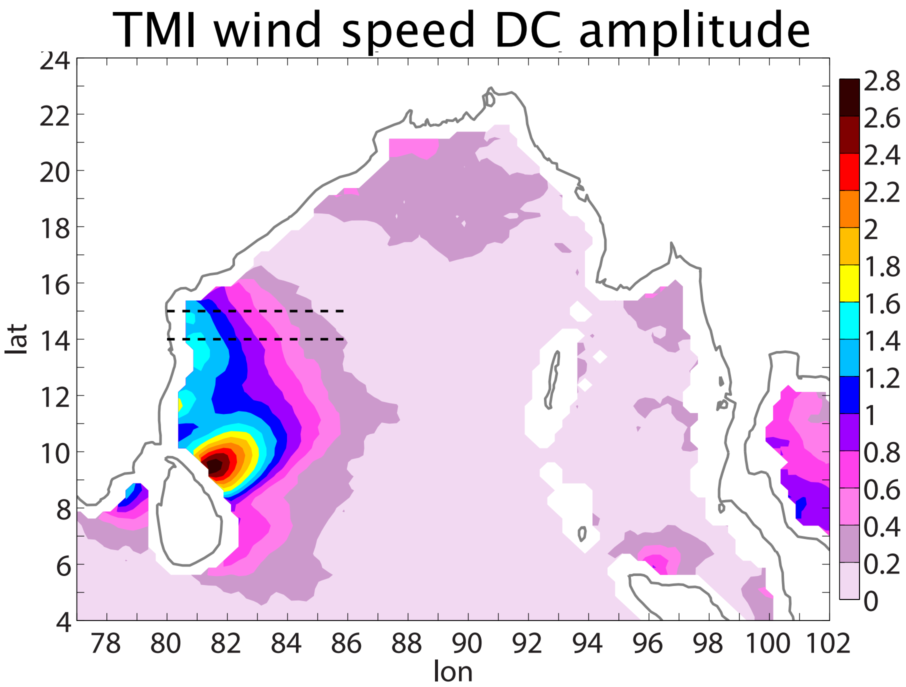




- A "blob" of deep convection exists in the western bay, where nearly all the rainfall varies diurnally.
- A zonal transect through the blob shows co-propagation of the land breeze and diurnal rainfall.
- The phase speed ≈18 m/s, consistent with a gravity wave of deep baroclinic structure forced by diurnal heating over India.

TMI wind speed also shows enhanced land-sea breeze in the western bay



TMI wind speed data are subsampled from days (1998-2014) with "steady" monsoon winds.

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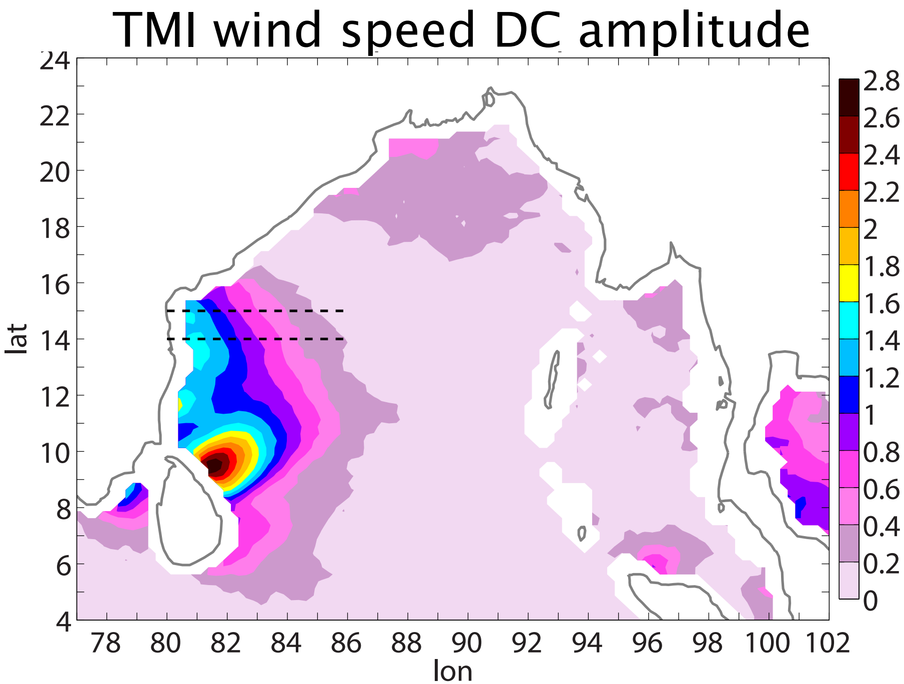
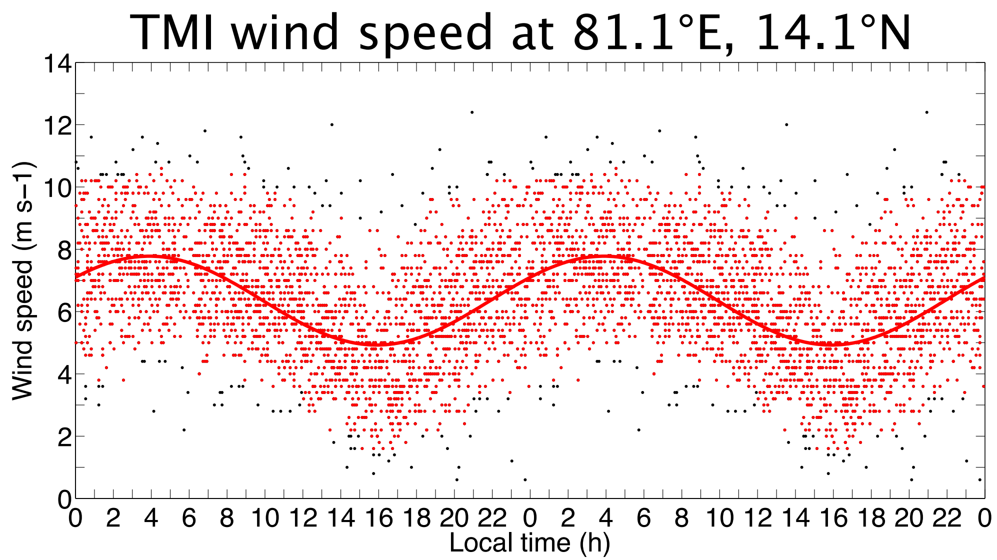
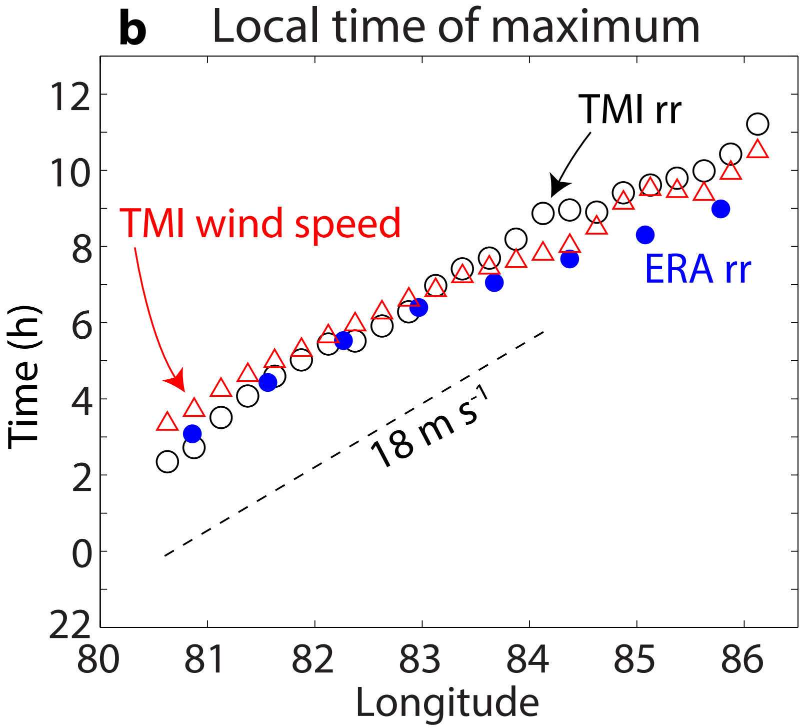




TMI wind speed data are subsampled from days (1998-2014) with “steady” monsoon winds.

TMI diurnal wind speed and rainfall maxima co-propagate into the bay

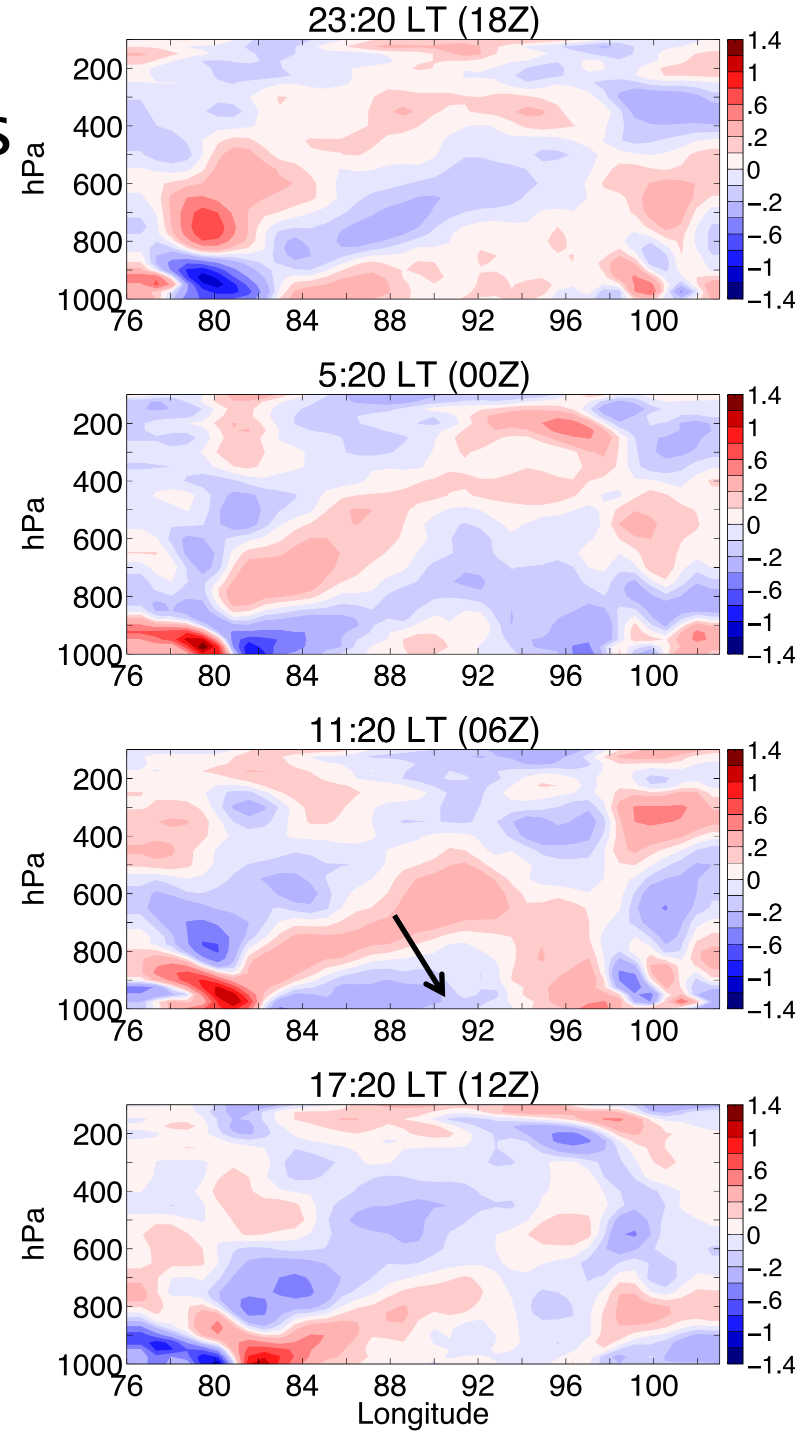
The wind speed maximum roughly coincides with the rainfall maximum, implying that convergence leads rainfall.



ERA-Interim winds show vertical propagation of the diurnal waves

Vertical section of horizontal wind divergence at 14°N shows the diurnal gravity waves propagate downward and eastward across the bay.

The waves have a fairly deep structure, with a vertical wavelength ≈ 11 km, in general agreement with linear wave theory (m = N/c).



Color = div. ($\times 10^{-5}$ s^{-1}) at 14°N in ERA-Interim, Jun-Oct 2003

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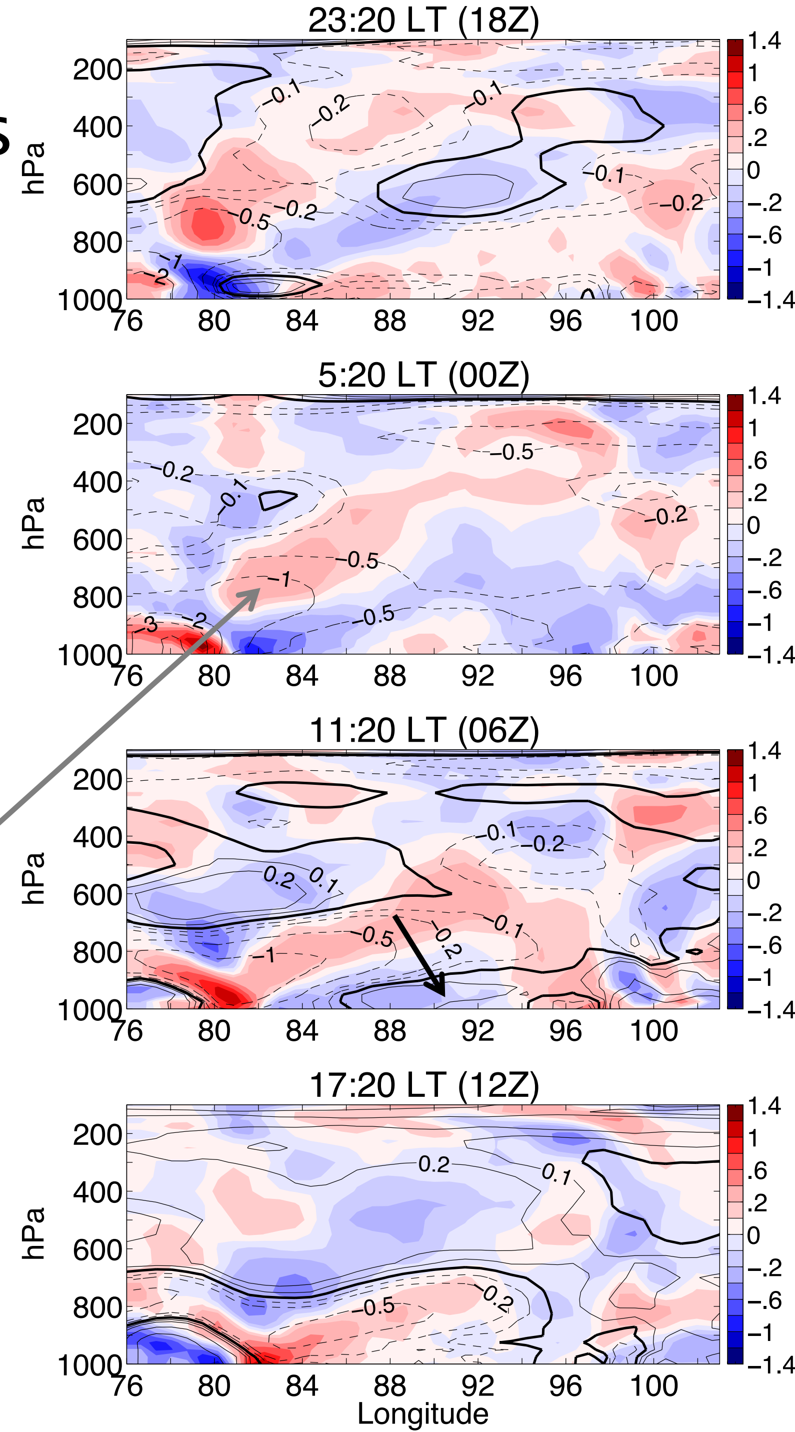
Vertical propagation of temperature signals is also consistent with gravity waves. Cooling near 800 hPa may help initiate offshore convection (Mapes et al. 2003, MWR).



Color = div. ($\times 10^{-5}$ s^{-1}) at 14°N in ERA-Interim, Jun-Oct 2003.
Contours = T anomalies

Summary: Diurnal convection-wind coupling

Tandem mission scatterometers and TMI resolve the diurnal cycle of surface winds in the Bay of Bengal.

Surface convergence and rainfall maxima co-propagate offshore with convergence leading by 2-4 h, implying that the land-sea breeze forces diurnal convection in the bay.

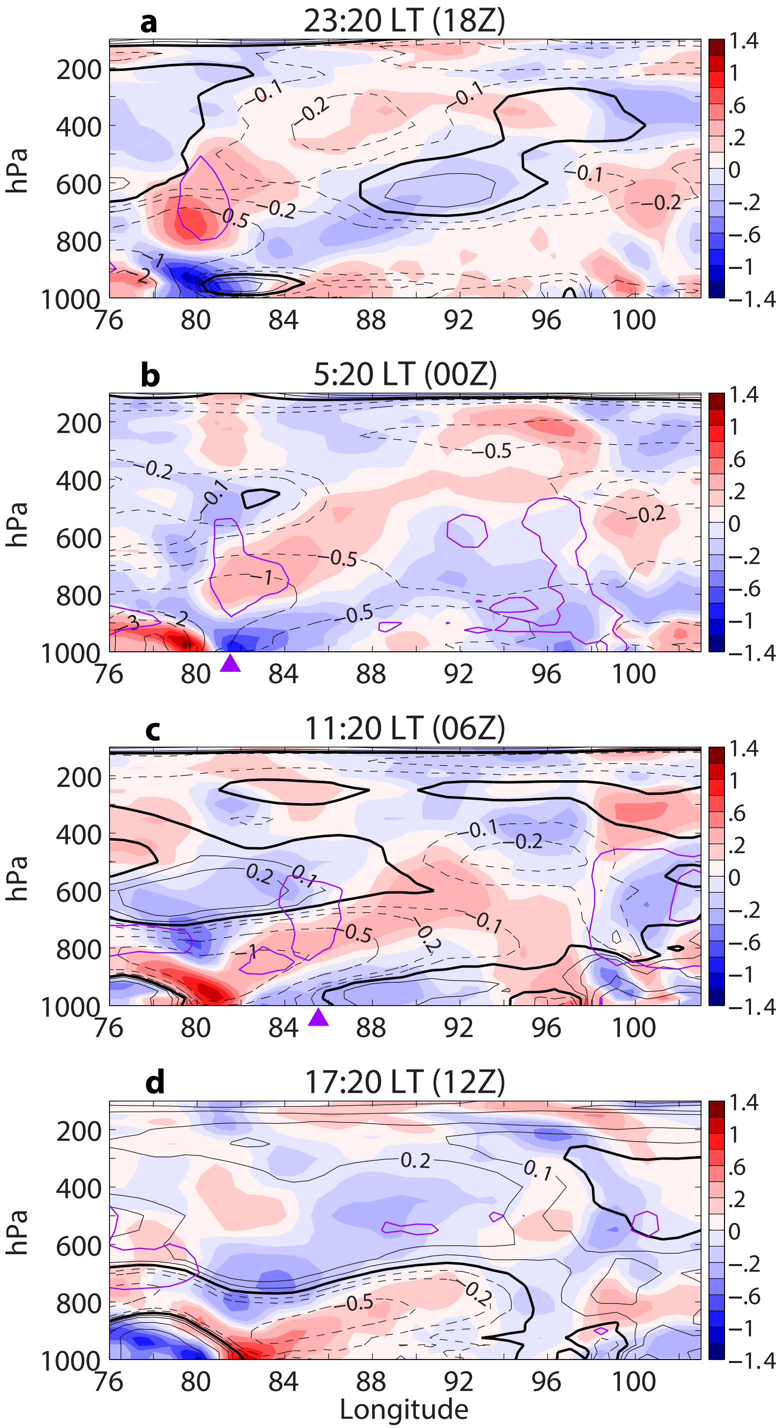
The phase speed ≈18 m/s, consistent with a gravity wave of deep baroclinic structure forced by diurnal heating over India.

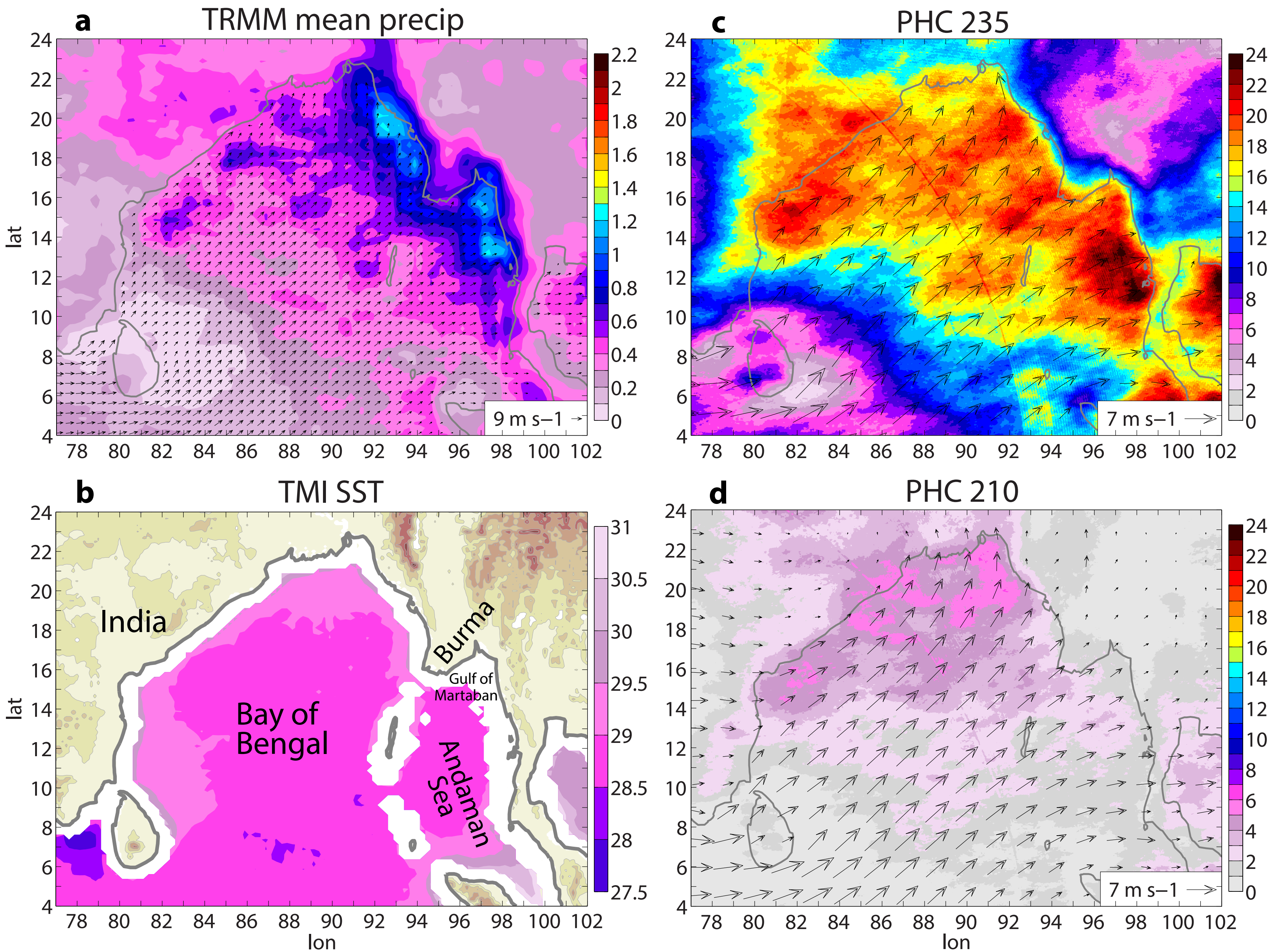
ERA-Interim shows vertical propagation of the diurnal gravity wave, with cool temperature anomalies overlying surface convergence.

Reference: Kilpatrick, T., S.-P. Xie, and T. Nasuno, Diurnal convection-wind coupling in the Bay of Bengal, submitted.

- 2°N

- CLWC contour overlaid (purple), 10^{-5} kg kg^{-1}



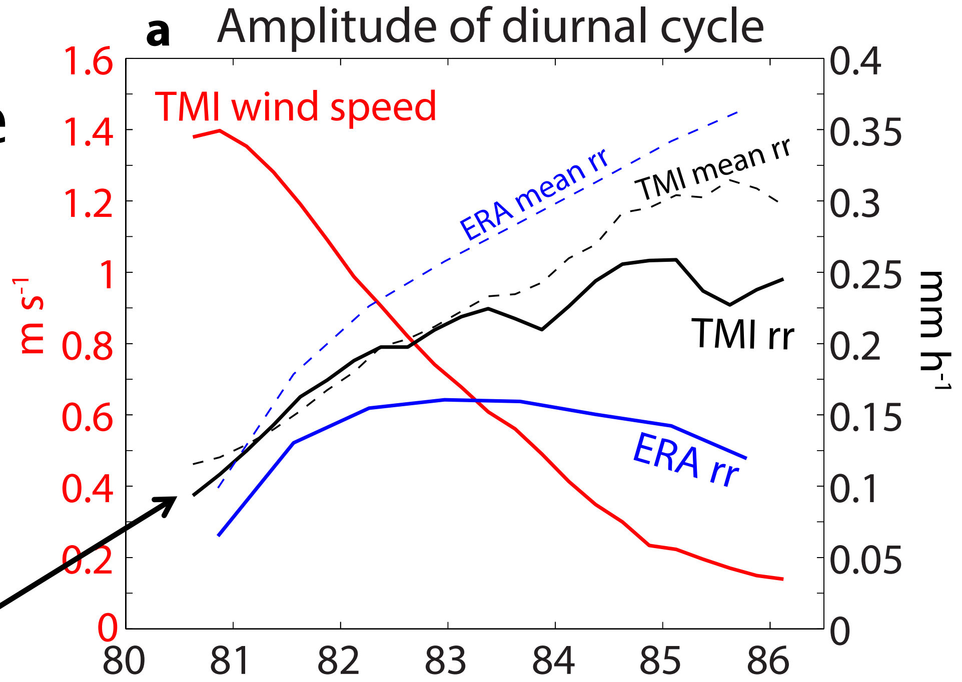


a
TRMM mean precip
9 m s–1
b
TMI SST
India
Burma
Gulf of
Martaban
Bay of
Bengal
Andaman
Sea
c
PHC 235
7 m s–1
d
PHC 210
7 m s–1
lat
lon

TMI diurnal wind speed and rainfall maxima co-propagate into the bay

Wind speed diurnal cycle decreases offshore, as in the tandem mission observations.

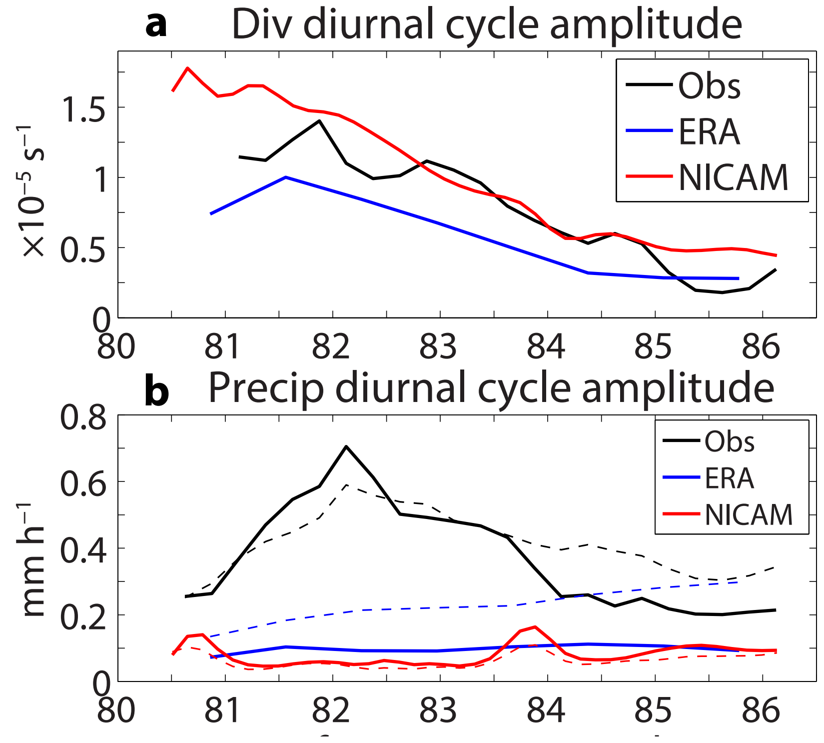
The rainfall diurnal cycle amplitude equals the mean rain rate, indicating that nearly all the rainfall varies diurnally.



Models underrepresent diurnal cycle of rainfall, despite accurate land-sea breeze circulation

Divergence and precipitation diurnal cycles decrease with distance from shore.

Models greatly underestimate amplitude of rainfall diurnal cycle.



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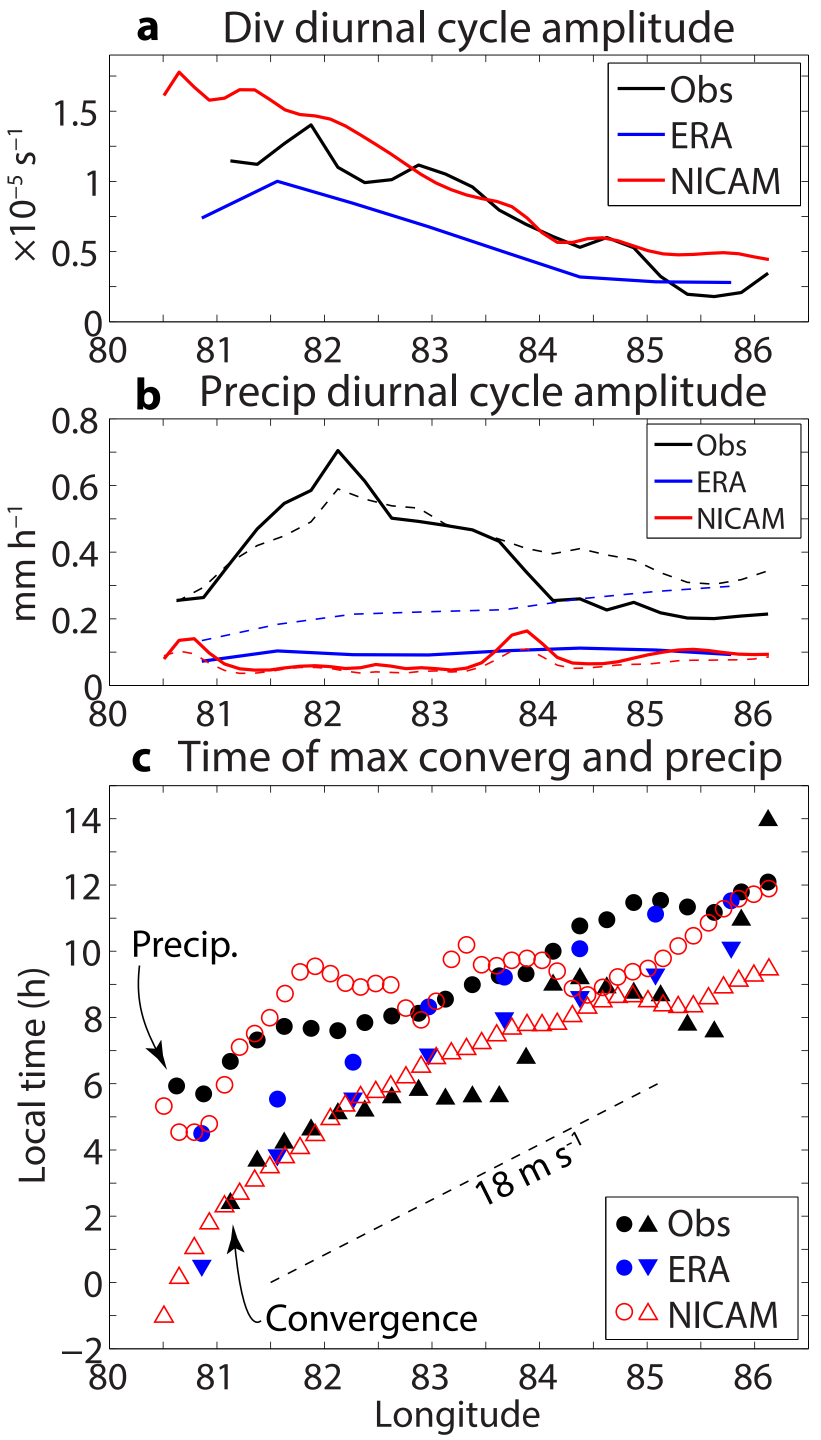
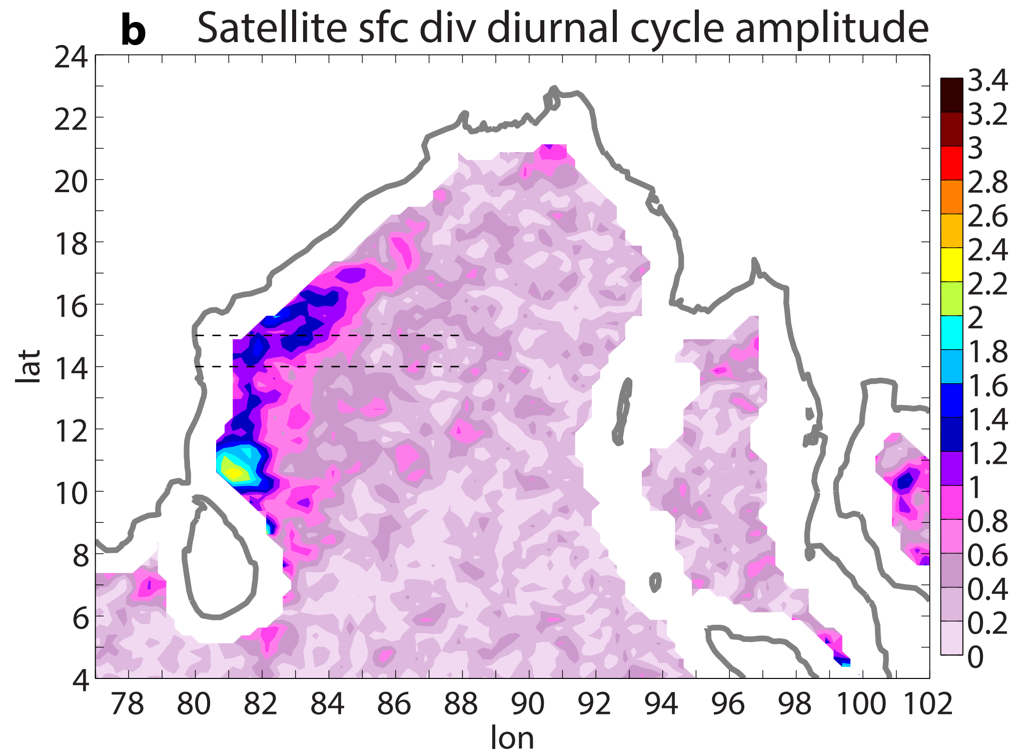
Model representation of land-sea breeze circulation looks pretty good.

→Both models show “slow” land breeze from coast to 81.5°E, and faster gravity wave offshore.

TRMM 3B42 rainfall peak lags ERA-Interim by 1-1.5 h.





- Pattern similar to diurnal difference

- 2°N

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